

INTEGRATED CIRCUIT DEVICES HAVING ACTIVE REGIONS WITH
EXPANDED EFFECTIVE WIDTHS AND METHODS OF MANUFACTURING
SAME

Related Application

This application claims the benefit of Korean Patent Application No. 2000-63711, filed October 28, 2000, the disclosure of which is hereby incorporated herein by reference.

Field of the Invention

The present invention relates generally to field effect transistors and, more particularly, to integrated circuit devices incorporating field effect transistors and methods of manufacturing same.

Background of the Invention

As the integration density of a semiconductor chip increases, the size of a semiconductor chip generally decreases. Accordingly, as a semiconductor device, such as a dynamic random access memory (DRAM) device becomes more minute, it may be difficult to ensure that a cell transistor (cell Tr) maintains a sufficient drive capability.

In the case of a DRAM device, although the size of a memory cell transistor may decrease, the threshold voltage across a memory cell transistor is still typically kept at about 1 volt based on the refresh characteristics of the DRAM device. The gate length of a memory cell transistor and the width of an active region within a memory cell transistor may decrease as the size of a semiconductor device is reduced. To maintain the threshold voltage across a memory cell transistor at about 1 volt,

channel density may be increased. Increasing the channel density, however, may cause the junction electric field to increase and the density of defects to increase, which may degrade the refresh characteristics of the DRAM device.

Also, a shallow junction is generally needed to reduce the size of a semiconductor device and to decrease the impurity concentration of a drain or a source region. Consequently, parasitic resistance may rapidly increase and the driving ability of a memory cell transistor (*e.g.*, the current through the cell transistor) may fall sharply.

As the size of a semiconductor chip decreases and the integration density increases, shallow trench isolation (STI) may be used to isolate individual devices from each other. STI is advantageous in that it may be used as an isolation technique in devices that have high pattern densities and it generally exhibits favorable isolation characteristics. The advantages of STI notwithstanding, if a transistor has an active region with a generally small width, then the threshold voltage across the transistor may decline.

Summary of the Invention

According to embodiments of the present invention, an integrated circuit device comprises a substrate that has a trench formed therein. An isolation layer is disposed in the trench and covers a first sidewall portion of the trench. A gate electrode is disposed on a second sidewall portion of the trench. The effective width of an active region, which may act as a transistor channel under the gate electrode, may be increased by the length of the second sidewall portion of the trench. Moreover, the increased channel width of the transistor may result in an increase in the current driving capability of the transistor.

In other embodiments of the present invention, a gate insulating layer is disposed between the gate electrode and the second sidewall portion of the trench, a buffer layer is disposed between the isolation layer and the trench, and a liner layer is disposed between the isolation layer and the buffer layer.

In still other embodiments of the present invention, the second sidewall portion of the trench comprises a layer that has been doped with an impurity, such as boron.

In further embodiments of the present invention, the trench may be formed by forming an oxide layer on the substrate, forming a mask on the oxide layer, patterning the mask to expose at least a portion of the oxide layer, and then etching the exposed portion of the oxide layer.

5 In still further embodiments of the present invention, the isolation layer may be formed by filling the trench with insulating material so as to cover the mask. The insulating material may then be planarized until a surface of the mask is exposed. The insulating material is then patterned so that the mask extends through a surface of the insulating material. Etching is performed to substantially remove the mask from the
10 upper surface of a mesa adjacent to the trench. The insulating material is etched so that the insulating material covers the first portion of the sidewall and exposes the second portion of the sidewall.

Brief Description of the Drawings

15 Other features of the present invention will be more readily understood from the following detailed description of specific embodiments thereof when read in conjunction with the accompanying drawings, in which:

FIGS. 1 - 8 are cross sectional views that illustrate integrated circuit devices having active regions with expanded effective widths and methods of manufacturing
20 same in accordance with embodiments of the present invention.

Detailed Description of Preferred Embodiments

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings
25 and will herein be described in detail. It should be understood, however, that there is no intent to limit the invention to the particular forms disclosed, but on the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims. Like numbers refer to like elements throughout the description of the figures. In the figures, the dimensions
30 of layers and regions are exaggerated for clarity. It will also be understood that when an element, such as a layer, region, or substrate, is referred to as being "on" another element, it can be directly on the other element or intervening elements may be

present. In contrast, when an element, such as a layer, region, or substrate, is referred to as being "directly on" another element, there are no intervening elements present.

FIGS. 1 through 6 are sectional views that illustrate integrated circuit devices having active regions with expanded effective widths and methods of manufacturing same in accordance with embodiments of the present invention. Referring now to **FIG. 1**, an integrated circuit device comprises a substrate **100**, such as a silicon substrate, that has a trench **200** formed therein. In more detail, a pad oxide layer **310** is formed on the substrate **100** to a thickness of about 100 Å using a conventional thermal oxidation. After forming the pad oxide layer **310**, a mask **400** is formed on predetermined regions of the substrate **100** and the pad oxide layer **310**. The mask **400** may comprise a silicon nitride layer and may be patterned using photolithography. A portion of the substrate **100** not covered by the mask **400** is etched using a photolithographic process, such as a shallow trench isolation (STI) process. Consequently, a trench **200** dividing a pair of mesas is formed in the substrate **100**. The depth of the trench **200** may vary depending on the type of semiconductor device being manufactured. In an exemplary embodiment, the trench **200** is formed to a depth of about 2500 Å.

Referring now to **FIG. 2**, the trench **200** is filled with an isolation layer **500** as part of the STI process. The isolation layer may comprise an insulating material, such as silicon oxide. After the isolation layer **500** is formed, the isolation layer **500** may be thermally treated to densify the isolation layer **500**. A chemical mechanical polishing (CMP) procedure may then be performed to planarize the isolation layer **500** until a surface of the isolation layer **500** is substantially level with the top surface **401** of the mask **400** such that the top surface **401** is exposed.

For the benefit of subsequent processes, the isolation layer **500** is further etched using an isotropic and/or an anisotropic etching process. For example, after the CMP process, the isolation layer **500** may be etched to reduce its thickness by approximately 1500 Å. As a result, the isolation layer **500** is patterned so that the top surface of the isolation layer **500** is lower than the top surface **401** of the mask **400**. Wet etching may be performed using a conventional oxide etchant in an isotropic etching process and dry etching may be performed with respect to a silicon oxide in an anisotropic etching process.

In other embodiments, a buffer layer **510** may be formed on the substrate **100** before forming the isolation layer **500**. The buffer layer **510** may alleviate stress between the silicon oxide of the isolation layer **500** and the silicon of the substrate **100**. The buffer layer **510** may comprise a silicon oxide layer, which can be transformed into a thermal oxide layer using an oxygen source.

Referring now to **FIG. 3**, after the isolation layer **500** is patterned, the mask **400** is removed using a conventional process, such as an isotropic wet etching process, to strip the silicon nitride comprising the mask **400**. After removal of the mask **400**, the surface of the isolation layer **500** is substantially level with the mesas in the substrate **100**, which are adjacent to the trench **200**.

Referring now to **FIG. 4**, the isolation layer **500** is further etched to form an isolation layer **500'** in which the upper sidewalls **205** of the mesas adjacent the trench **200** are exposed. The isolation layer **500** may be selectively etched, for example, by wet etching using an oxide etchant in an isotropic etching process and/or by dry etching using an etchant having a relatively high selectivity ratio with respect to the silicon oxide of the isolation layer **500** and the silicon of the substrate **100**, respectively. The isolation layer **500** may be etched to reduce its thickness by approximately 500 Å so that the top surface of the isolation layer **500'** is about 500 Å lower than the upper surface **105** of the mesas in the substrate **100**. In addition to etching the isolation layer **500**, the buffer layer **510** may also be etched so as to remove portions thereof.

After etching the isolation layer **500** to form the isolation layer **500'**, the upper sidewalls **205** of the mesas adjacent to the trench **200** are exposed. The length of the upper sidewalls **205** may vary in accordance with embodiments of the present invention. By controlling the extent to which the isolation layer **500** is etched, the lengths of the upper sidewalls **205** may be set. In exemplary embodiments of the present invention, each of the upper sidewalls **205** may be approximately 500 Å long.

In some embodiments of the present invention, an upper sidewall **205** may be at least 15% of the length of an upper surface **105** of a mesa adjacent the trench **200**.

In other embodiments, an upper sidewall **205** may be approximately 30% - 60% of the length of an upper surface **105** of a mesa adjacent the trench **200**. When the isolation layer **500'** is formed to be as thin as possible without losing its isolation

characteristics, the lengths of the upper sidewalls 205 exhibit their maximum values. It is, therefore, possible to increase the lengths of the upper sidewalls 205 as long as the isolation layer 500' is not thinned to an extent that the isolation characteristics of the isolation layer 500' are degraded.

5 Referring now to FIG. 5, after the isolation layer 500' is formed, a sacrificial oxide layer 350 or a pad oxide layer used for ion implantation is formed on the upper surface 105 of the substrate 100 and the upper sidewalls 205. Before the sacrificial oxide layer 350 is formed, however, the substrate 100 may be washed. After forming the sacrificial oxide layer 350, an impurity layer 600 is formed in the upper sidewalls 10 205 by ion implantation and may be used to control the threshold voltage. Before the impurity layer 600 is formed, well ion implantation or field ion implantation may be performed. The well ion implantation and/or the field ion implantation procedures may be performed using conventional processes typically used to form a transistor.

When using NMOS technology in the manufacture of DRAMs, the impurity 15 layer 600 may be formed by doping a p-type impurity, such as boron. The impurity layer 600, which may be used to control the threshold voltage, is disposed beneath the upper surface 105 of the substrate 100 and beneath the surface of the upper sidewalls 205. The impurity used in the doping process may be extracted toward an insulating layer (not shown), which is subsequently formed on the substrate 100. Due to the 20 impurity extraction or segregation, the impurity concentration of the impurity layer 600 may be reduced near the upper sidewalls 205.

To address this problem, the impurity layer 600 used for controlling the threshold voltage may be formed by angle implantation. That is, ion impurities may be implanted at an oblique angle with respect to a plane formed by the non-etched 25 portion of the substrate 100. The inclination angle of the ion implantation process may be varied, and the angle implantation process may be performed by symmetric insertion or rotating insertion. Consequently, using angle implantation, the impurity concentration in the upper sidewalls 205 may be increased. The impurity layer 600 used for controlling the threshold voltage has a substantially uniform depth and is 30 disposed beneath the upper surface 105 of the substrate 100 and beneath the surface of the upper sidewalls 205.

Referring now to **FIG. 6**, the sacrificial oxide layer **350** used for the ion implantation is removed by an isotropic etching process, such as a wet etching process. A gate insulating layer **700**, which may comprise a conventional oxide material, is then formed on the exposed portions of the mesas adjacent the trench **200** (i.e., the upper surface **105** of the substrate and the upper sidewalls **205**). The gate insulating layer **700** may have a thickness of about 50 Å.

After the formation of the gate insulating layer **700**, a conductive material is deposited on the gate insulating layer **700**, thereby forming a gate electrode **800**. As illustrated in **FIG. 6**, the gate insulating layer **700** is interposed between the gate electrode **800** and the upper surface **105** of the substrate **100** and also between the gate electrode **800** and the upper sidewalls **205**.

Advantageously, the effective width of an active region, which acts as a transistor channel under the gate electrode **800**, may be increased by adding the lengths of the upper sidewalls **205** to the length of the upper surface **105** of the substrate. Thus, the effective width of an active region comprises the lengths of both upper sidewalls **205** along with the length of the upper surface **105** of the substrate. After the gate electrode **800** is formed, drain/source regions are formed, thereby forming a transistor having an active region with an expanded effective width and, therefore, a channel with an expanded effective width.

The current driving capability of a memory cell transistor is inversely proportional to the channel length and is proportional to the width of the gate electrode **800** (i.e., the width of a channel). Consequently, the increased channel width of the transistor may result in an increase in the current driving capability. Thus, even in more highly integrated chips that use smaller devices, the effective width or effective area of an active region may be increased in accordance with embodiments of the present invention, which may preserve the current driving capability of a transistor.

For example, if the upper surface **105** of the substrate **100**, which has been defined by photolithography, has a width of 1000 Å and each of the upper sidewalls **205** has a width of 500 Å, the effective width of an active region is 2000 Å. In contrast with conventional design rules in which the active region width corresponds

to the length of the upper surface 105, the effective width of an active region may be doubled.

As described above, in accordance with embodiments of the present invention, it is possible to increase the effective width of an active region in a transistor, which may obviate the need to increase channel density for the purpose of maintaining the transistor threshold voltage. Advantageously, embodiments of the present invention may improve the refresh characteristics of a DRAM device by inhibiting increases in junction electric field and/or reducing the density of defects.

FIGS. 7 and 8 are sectional views that illustrate integrated circuit devices having active regions with expanded effective widths and methods of manufacturing same in accordance with further embodiments of the present invention. As shown in **FIG. 7**, after the trench 200 is formed by selectively etching the substrate 100 with the use of a mask 400 and after the buffer layer 510 is formed, a liner 550, which may comprise a silicon nitride layer, is formed on the buffer layer 510. The liner 550 may alleviate stresses caused by the isolation layer 500 during subsequent thermal oxidation and/or annealing processes. Also, the liner 550 may inhibit the occurrence of defects, such as pits, which may form on the substrate 100. Referring now to **FIG. 8**, after the isolation layer 500 is formed on the liner 550, an isolation layer 500' is formed by etching the isolation layer 500. Subsequently, a gate insulating layer 700 and a gate electrode 800 are formed. The embodiments of **FIGS. 7 and 8** may provide an active region with an enhanced effective width similar to the embodiments of **FIGS. 1 - 6**. In addition, the embodiments of **FIGS. 7 and 8** may reduce defects caused by the influence of subsequent processes on the isolation layer 500'.

In concluding the detailed description, it should be noted that many variations and modifications can be made to the preferred embodiments without substantially departing from the principles of the present invention. All such variations and modifications are intended to be included herein within the scope of the present invention, as set forth in the following claims.